BELLCOMM, INC.
1100 Seventeenth Street, N.W. Washington, D.C. 20036

SUBJECT: A Preliminary ELM/Unmanned LRV Mission Plan for the Apennine Front-Hadley Rille Area - Case 340

DATE: May 31, 1968

FROM: N. W. Hinners
F. El-Baz
A. F. H. Goetz

ABSTRACT

An Extended LM mission to the Appenine Front-Hadley Rille area of the Moon, constrained to 4 EVA's, 3 days staytime, and 750 lb payload, can yield satisfactory scientific return when the payload includes flying units for increased astronaut mobility. A 1/3 increase in both staytime and payload would more than proportionally increase return. Use of an unmanned lunar roving vehicle in lunar exploration, with rendezvous at a manned landing site, is briefly considered. Problem areas uncovered which must be solved are: unfavorable lighting at the site during landing; line-of-sight communications; and steep topography under the landing approach path.

(NASA-CR-95565) A PRELIMINARY ELM/UNMANNED LRV MISSION PLAN FOR THE APPENINE FRONT-HADLEY RILLE AREA (Bellcomm, Inc.) 19 p

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MEMORANDUM FOR FILE

I. INTRODUCTION

As one of a series of preliminary mission plans for post-Apollo lunar exploration, this memorandum presents a plan for a mission to the Apennine Front-Hadley Rille area. This is one of the six sites considered by the Group for Lunar Exploration Planning (GLEP) Site Selection Subgroup as a candidate for post-Apollo exploration utilizing mobility aids for the astronauts which would give them a radius-of-operation of at least 5 km. A further consideration is the desire expressed at the Santa Cruz Lunar Exploration Conference to see unmanned spacecraft utilized in the post-Apollo period, either independent of, or in conjunction with, manned missions. For purposes of investigating the potential of combined manned/unmanned missions, we briefly consider here the special case where an unmanned lunar roving vehicle (ULRV) lands unmanned, conducts a lengthy scientific traverse, and effects a rendezvous with the Extended LM (ELM) at the end of the traverse.

There will be continual revision and updating of this plan. It is being circulated now to elicit critical comment from other groups involved in mission planning.

II. SITE DESCRIPTION AND SETTING OF APPENINE FRONT-HADLEY RILLE SITE*

ORBITER V: V-26 FRAMES: 104-107 (s)

LAC CHART: 41 COORDINATES: 26° 52' N, 3° 00' E

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*This section has been taken, with minor modification, from the site descriptions provided by a Site Selection Subgroup of the GLEP. The authors participated in that group. A full list of participants can be found in the Appendix.

The Apennine Front-Hadley Rille area (Fig. 1) is located at the eastern rim of the Imbrium Basin, just west of the scarp of the Apennine Front. This site is important among those proposed in that it may provide access to a major portion of lunar history and to a major physical unit of the lunar crust. Such access comes from over 1 km of vertical relief resulting from the combination of the Apennine Mountains scarp, the rim of the Imbrium Basin and the rille. The proximity of the site to the scarp permits the geophysical study of primary physical features of continental scale.

In the Apennine Front-Hadley Rille site we expect to find extensive exposures of materials believed to have formed during a long span of lunar history. This historical sequence may run from materials that constitute original lunar "crust" to relatively young materials derived from that crust. The oldest crustal materials in the area, possibly exposed in the lower part of the Apennine Front to the east of the proposed landing area, should provide data bearing directly on the problems of the primary physical and chemical composition of the Moon and thus, indirectly, of the Earth.

Photogeologic investigations of the site strongly suggest that materials (the Fra Mauro formation) derived from the central portion of the Imbrium Basin have been deposited on top of the lower, pre-Imbrian materials of the Apennine Front. The deposition of the overlying and apparently younger materials probably occurred as a consequence of the very large impact event that formed the Imbrium Basin. Our present understanding of the processes associated with impact events indicates that these apparently younger materials were derived from depths of several tens of kilometers in the Moon and, in fact, offer one of our best chances to examine "primitive" planetary materials which have not been affected by later planetary differentiation processes.

Several geophysical measurements can be made at the Hadley Rille site that will help elucidate the large scale structure of the area. Observations of seismic surface waves, made as a function of azimuth, should reveal differences in the subsurface structure beneath the Apennine Mountains and Mare Imbrium. If seismic events occur east of the Appenines, then perhaps the arrival times of refracted body waves can be used to determine the structure beneath the mountains in much the same manner as used several decades ago in the classic seismic studies of the subsurface structure of the Sierra Nevadas with seismic stations located in California.

The concept of isostasy -- that high mountains are made up of rocks of relatively low density and "float" in a higher density material -- was developed in response to careful measurements of gravity made a century ago at the base of the highest mountain range on Earth, the Himalayas. It seems possible to test the application of the concept to the Moon by measurement of gravity near the Apennines. Even a short traverse of 10 km might provide data that are sufficient to set limits on the isostatic balance of the mountain range. Because the value of gravity on the Moon is only about one-sixth that of the Earth, and because the long-term strength of rocks in the outer few tens of kilometers is expected to be roughly the same in the lunar environment as terrestrially, it is entirely possible that isostasy may not be a general phenomenon on the Moon.

The lunar samples returned from this site can be examined for evidence of the existence in past times of the presence of a lunar magnetic field. This will require careful work at rock ledges in the rille and at the Apennine scarp to collect material that can be identified as originating from a particular location in the stratigraphic sequence.

Determination of heat flow at this site, when compared with the values of heat flow obtained at other lunar sites, will be used to set limits on the lateral distribution of heat sources. In particular, it will be important to learn whether the heat flow is significantly different beneath large mountain ranges and the maria. The Hadley Rille site is sufficiently near the Apennines to reveal any significant difference in regional heat flow associated with the mountains.

The implications of sinuous rilles, such as Hadley Rille, are a subject of much debate. The most important possibility is that they are somehow associated with the escape of volatile substances from the lunar interior. The geochemical constitution of those volatiles or "fluids" bears directly on the evolution of planetary atmospheres, hydrospheres, and crusts and on the concentration of mineral resources.

The sinuous rilles have been interpreted by several people as erosion channels with the source of the material coming from the "head" found at the southern end of the rille. If this is true, it is important to determine what the eroding material was as a key to investigating lunar interior processes, e.g., degassing. Studies of the rille morphology, combined with hydrologic theory, can lead to estimates of the "fluid" viscosity. Analysis of the material deposited in the channel bottoms (bedding, grain size, density as a function of position) would give hard data on the physical properties of the "fluid" as would information on the kind and strength of material forming the channel walls and floor.

A prime objective of lunar exploration is the search for organic or proto-organic material, processes, and environments. A place to look for these is one where volatiles may have existed, thus the sinuous rilles and associated permanent shadowed zones are potential locations for investigations in these areas.

The proposed landing site (Figs. 1 and 2) is located on regionally flat mare terrain east of a segment of the Hadley Rille. Within 5 km of the landing point are portions of the Hadley Rille, the crater Hadley C and parts of the Apennine Front. The mare material here and nearby fills topographically low areas and has a low surface density of small primary impact craters, which suggests a relatively young age for this material. The mare surface is pock-marked by secondary impact craters from the large impact crater Autolycus that lies north of this area. The hummocky deposits of the probable maar Hadley C apparently overlie these secondaries. The mare surface also is apparently broken by renewed movement along the much larger older tectonic breaks. These faults can be examined on the ground geologically and geophysically. The old faults are both concentric and radial with respect to the Imbrium basin.

The inner slopes of the rille are steep (17°) and typically block-strewn. At least three ledges of bedrock appear to be exposed in the rille aggregating 100 meters of beds. The blocks do not occur in the mare terrain away from the rille.

On the east side of the area is the break in slope marking the contact of the mare material with the potentially old rocks exposed on the Apennine Front. Some 1,280 feet of beds may be exposed on this slope. Blocks occur at the crest of the ridge directly east of the site and probably occur downslope as well. These may be fragments from the Fra Mauro formation exposed on top of the mountains and which mantle the pre-Imbrian rocks of the mountain block.

III. SCIENTIFIC OBJECTIVES

Considering the discussion above, the following specific scientific objectives can be established for an exploration of the Apennine Front-Hadley Rille site. No priority order is intended.

1. Investigate and sample the mare fill to correlate with other mare sites with regard to age, composition, and processes.

2. Study the structure of and obtain oriented samples from rock exposures on the rille walls for purposes of age dating, conducting compositional studies, and looking for remnant magnetism.

3. Obtain core samples of rille fill in an effort to decipher the origin of the rille. In particular, look for sedimentary bedding, fragment-size sorting and chemical alterations.

4. Study structural relationships at the Apennine scarp and obtain samples of suspected Fra Mauro material. Look for underlying material also.

5. Look for and obtain samples of Apennine material from ridge crests.

6. Study lunar mass wasting processes in rille and at scarp.

7. Deploy scientific station to monitor lunar seismic events as a function of azimuth (waves coming from the east pass under mountains), heat flow (probably affected by mountains and rille), magnetism, atmosphere (look for degassing in rille), and other geophysical phenomena.

8. Conduct geophysical traverses (seismic, gravity, magnetic) to delineate subsurface rille structure and the Apennine-mare interface and to test the isostatic adjustment hypothesis.

9. Obtain samples from depth ($\sim$ 10 ft) to check on constancy of cosmic ray flux as a function of time, to obtain material which may have "cold-trapped" volatiles, and to obtain material which may contain organic material.

10. Investigate the crater Hadley C and its relationship to the rille. Obtain samples of crater rim material.

11. Retrieve samples from ULRV.

IV. GROUNDRULES

Staytime: 3 days

Mobility: 2 LFU's, 180 lbs each, line-of-sight operation, 3 propellant loadings of 300 lbs each available from the ELM, 5 km maximum radius-of-operations, rescue capability with one LFU.

The groundrules below were established for the initial mission planning efforts in order that there be a common basis for comparison of the several plans.

EVA's: (from MSC preliminary guidelines)
Only one EVA on the first and last day of lunar stay.

ULRV : Landed unmanned, 500 km range, rendezvous with ELM, collect samples and conduct geophysical investigations on traverse.

V. ULRV TRAVERSE

In the combined ELM/Unmanned LRV (ULRV) mission, the ULRV is landed unmanned 500 km from the ELM site about six months prior to the ELM mission. Its job is to conduct an unmanned scientific traverse along a pre-planned route, including the deployment of a geophysical net, and to end up at the ELM site with samples collected along the traverse. The astronauts then retrieve the samples for return to Earth.

The configuration of the ULRV is not yet clear but it is estimated that a landed system, including the ULRV and other science payload, could weigh ∿ 1500-3000 lbs. The ULRV presumably would be equipped with television, communications and navigation, sampling tools, sample packaging equipment, diagnostic analytical equipment, deployable Remote Geophysical Monitors, and other traverse science, including a gravimeter and magnetometer.

The possibility of landing the ULRV about 500 km away from the Apennine-Hadley ELM landing site is looked into very briefly. Four possible 500 km* traverses for such a vehicle are considered, all ending up at Hadley C. These are shown in Fig. 3, which is a reproduction of Lunar Orbiter IV medium resolution frame 114. At a scale of about 1:3,000,000, it depicts Hadley Rille in the central area and the Apennine Mountains between Mare Imbrium to the west and Mare Serenitatis to the east.

Traverse 1

a. The landing area is in the Sulpicius Gallus region of southwestern Mare Serenitatis and directly south of a complex of linear rilles. The surface materials in this region are conspicuously dark and are probably young volcanic rocks which have mantled not just the pre-existing mare material but also the plains-forming highland terrain in the immediate vicinity.

b. The traverse line proceeds in a north-northwest direction passing through lighter and probably older materials of Mare Serenitatis and then proceeds westward at the contact between the latter and Mare Imbrium.

c. The line then crosses Mare Serenitatis to Mare Imbrium, proceeding south-southwest through Apenninian plains-forming materials usually referred to as the Fra Mauro Formation. It then crosses Hadley Rille and finally ends at the crater Hadley C.

Traverse 2

a. The landing area is in northern Mare Serenitatis and south of the crater Alexander. The traverse crosses first a series of highland units characterized by flat nonhummocky to hummocky terrae believed by some to be ejecta, probably from the Imbrium basin.

b. The traverse line crosses the contact of highland units and the dark materials of Mare Serenitatis and continues in a southwesterly direction across several regions of bright mare surfaces that may be covered by ray materials.

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*Straight-line distances are assumed. Deviations for scientific and navigational purposes could add significantly to the range of the described traverses.

c. The line then crosses Mare Serenitatis to Mare Imbrium, proceeding south-southwest through Apenninian plains-forming materials usually referred to as the Fra Mauro Formation. It then crosses Hadley Rille and finally ends at the crater Hadley C.

Traverse 3

a. The landing area is in southern Mare Imbrium and west of the ghost crater Wallace. The traverse line goes eastward to the southern rim of that crater where it crosses a Copernican ray and a small crater chain.

b. The traverse line proceeds from the southern rim of the ghost crater Wallace in a northeast direction, passing through Mare Imbrium materials, the Apennine Bench formation and, finally, the Palus Putredinis mare materials until it reaches the Hadley C crater.

Traverse 4

a. The landing point is in the central region of Mare Imbrium in an area which is heavily populated with fresh-looking wrinkle ridges. The traverse line crosses one of the ridges and proceeds eastward toward the northern rim of the crater Archimedes.

b. The traverse line proceeds from the rim material of Archimedes to the mare material which is covered west and south of the crater Autolycus by freshly exposed bedrock usually designated "slope material".

c. Proceeding to the southeast, the traverse line crosses an area covered by hummocks of the Fra Mauro Formation and the light units of Palus Putredinis until it reaches the relatively dark mare material in which Hadley C is situated.

Each traverse has certain unique features. Traverses 1 and 2 offer greater potential geophysically in that they cross from one large mare to another through a region which appears at one time to have been an extension of the Apennines. It has been argued, however, that the subsurface structure may be so complicated as to be undecipherable from a simple traverse and that less complex areas should be investigated first. Traverse 1 offers the additional merit that it would originate at an area much like one of the other potential post-Apollo sites (Littrow Rilles). An unmanned landing there might negate the necessity for the Littrow mission <u>or</u> be a supplement to it.

Traverse 3 includes the Apennine Bench material, a possible volcanic ash or flow deposit. Traverse 4 is the only one which includes the central portion of a mare basin and offers the geophysical opportunity to obtain a subsurface mare basin profile. The approach to the Front offers a good opportunity to check for isostasy. Traverse 4 could be modified to include a segment reaching the Apennine Bench material but would have to be lengthened almost 200 km in order to investigate the central basin area.

In all cases, the ULRV could have utility at the ELM site in addition to the sample delivery. It could conduct a site survey, thus possibly doing away with the requirement for high resolution photography at the landing site and might well carry a landing radar beacon. Since it has a communications capability, it might be feasible to use the ULRV as a transponder for out-of-line-of-sight communications during the ELM mission. All described functions would require a very high reliability for the ULRV in order to guarantee its utility at the end of the traverse.

VI. ELM SURFACE MISSION

A 3 day extended LM mission to the Hadley Rille area would include 4 EVA's, a 5 km mobility radius-of-action, a rendezvous with a ULRV and the use of 2 LFU's. Figure 1 shows the area in question, on an orbiter medium resolution photograph, at the foot of the Apennines Mountains with a 5 km radius circle drawn about the landing point. Figure 2, a high resolution Orbiter photograph, shows the area in detail along with the LFU traverse outlines.

Sufficient propellant is available for 3 individual LFU traverses. During each of the first two LFU traverses the second LFU and an astronaut remain near the ELM for rescue purposes. The last LFU traverse is made mostly within walkback range of the ELM so that rescue capability is not needed. On

Figure 2, the Roman numeral designates the EVA number and the Arabic numeral the stop number. Below is a sequential outline of potential EVA's. The numbers in brackets refer to the specific scientific objectives denoted in Section III.

Day 1, EVA I (3 hrs)

Both astronauts take part in the following duties:

Collect contingency sample
Deploy S-band antenna
Inspect ELM
Deploy staytime extension equipment
Rendezvous with the ULRV for sample retrieval [1]
Collect preliminary sample [1]
Unload LFU's

Day 2, EVA II (3 hrs)

Both astronauts: Fuel LFU's (1/2 hr)

First astronaut: Conduct LFU traverse (2 hrs)

Station 1 — Apennine Front-mare contact (1 hr) [1, 4, 6, 9] Distance: 3.3 km from ELM

Station 2 — Top of ridge (1 hr) [5, 6, 9] Distance: 2.0 km from Station 1

Station 3 — Return 5.2 km to ELM; total 10.5 km Maximum payload: 175 lbs

Second astronaut: Inspect landing area (1/2 hr) [1, 9]
Deploy ALSEP (2 1/2 hr) [7]
Conduct Active Seismic Experiment
Stand-by for rescue

Day 2, EVA III (3 hrs)

Both astronauts: Fuel LFU (1/2 hr)

First astronaut: Conduct LFU traverse (2 hrs)

Station 1 — Bottom of Hadley Rille (1 1/2 hrs) [2, 3, 6, 9] Distance: 3.2 km from ELM

Station 2 Rim of Hadley C (1/2 hr) [10]
Distance: 4.8 km from Station 1

Station 3 Return 4.7 km, total 12.7 km
Maximum payload: 95 lbs

Second astronaut: Walk to edge of rille to maintain radio contact with LFU in bottom of rille. Investigate and sample edge of rille. (2 hrs) [1, 2, 6]

Day 3, EVA IV (3 hrs)

First astronaut: Conduct local LFU traverse (1 1/2 hrs)
Assist in sample loading and ascent preparations after traverse

Station 1 2 sets of crater pairs (1/2 hr) [1]
Distance: 2.5 km from ELM

Station 2 Rille and crater edge (1/2 hr) [1, 2, 6] Distance: 1.5 km from Station 1

Station 3 Rille edge promontory (1/2 hr) [1, 2, 6] Distance: 3.0 km from Station 2

Station 4 Return 1.4 km to ELM, total 8.4 km
Maximum payload: 105 lbs

Second Astronaut: Conduct local investigations [1]
Adjust ALSEP experiments
Prepare samples for return

Using nomographs supplied by MSC for LFU capability, it was found that there is sufficient payload available in all the above LFU traverses, the minimum being 95 lbs. Probably about 25 lbs will be used for communications and navigation equipment. It would probably be desirable on the traverses to take a powered hand-drill ($\sim$ 25 lbs) and bring back about 25 lbs of sample from each stop or 50 to 75 lbs per LFU traverse. Some of the sample will have to be left behind as only $\sim$ 80 lbs can be returned to Earth, including that collected from the ULRV. The total ELM scientific payload breakdown, keeping within the 750 lb total, is:

2 LFU's	360
Communications and navigation	25
Geologic equipment, cameras, film, etc.	25
Hand-drill	25
Return sample containers	35
Advanced ALSEP	280

VII. EVALUATION OF THE ELM MISSION

One can accomplish a satisfactory number of scientific objectives on a 3 day ELM mission to the Apennine Front-Hadley Rille site. A successful mission depends critically, however, on everything going with clockwork precision during the crowded EVA periods. The limiting factor in the exploration appears to be time, since some points of interest cannot be investigated in the three days (e.g., interior of Hadley C, intersection of Hadley C with rille, more and higher ridges in Front) and more time could be spent at traverse stops. The LFU has abundant capability for the mission described and could provide one or two more stops per traverse, time permitting.

An additional day of staytime would be consistent with the LFU capability of 3 traverses. However, the ridge traverse would include more stops and go higher. We would then add a walking traverse to the mare-Front contact. Such a change might require moving the landing site to the mare just northeast of Hadley C, between the rille and the Front, since at the present site ridges higher than the first are beyond the mobility limit of 5 km.* At the site northeast of Hadley C, one has access to several ridges of high relief while still being within reach of Hadley C and the rille. The main problem is that there is no high resolution photography of the region (the high resolution cuts off at the south edge of Hadley C).

A further problem in the general Apennine-Hadley region is lighting. In order to have access to the desirable features within 5 km, one must land near the Front. The steep topography there means that the landing site will be in shadow during most of the favorable landing lighting conditions.

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*This is not believed to be firm. If communications problems are solved for the 5 km distance, which they must be, there is no obvious reason why the range cannot be extended to ~ 10 km.

An area of large relief such as the area at this site presents many places where line-of-sight communication will not be possible (e.g., in the rille, in even small craters, on certain ridges). There is need to study the communications problems at these sites and possibly to develop a system such as transponders, to circumvent the problem.

Use of a manned LRV at this site does not appear mandatory since most of the traversing is "vertical" or to rather well defined points where the object is to get there in as short a time as possible. This assumes that the geophysical traversing was done by the ULRV.

Payload delivery to the site is not sufficient for, in the 750 lbs, one cannot accommodate an advanced ALSEP ($\sim$ 400 lbs), the Lunar Surveying System ($\sim$ 70 lbs), transponders, or spare life support equipment. A minimum of 1,000 lbs would seem adequate. Likewise, the 100 lbs return payload capability is inadequate, particularly in view of the sample collected from the ULRV, and the lack of time for much sample selection in-situ; 200 lbs returned to Earth would be more reasonable.

VIII. FUTURE PLANS

The described mission plan is preliminary in that it was prepared on a short time-scale for inclusion in the NASA Lunar Exploration Plan and was constrained by somewhat arbitrary ground rules. The next iteration, in progress, will analyze the site in terms of desirable payload and staytime and use of the ULRV in a manned mode. It will incorporate the geological analysis undertaken by the U.S.G.S. and will consider engineering analyses such as conducted by Valley[1]. Finally, the ULRV traverse will be investigated in more detail utilizing Orbiter photography and NASA contractor-produced vehicle analyses.

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Attachments
References
Figures 1-3

APPENDIX

Members of the Site Selection Subgroup of the Group for Lunar Exploration Planning who participated in the Site Selection Meeting of December 8-9, 1967

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Farouk El-Baz	Bellcomm, Incorporated
Paul Gast	Lamont Geological Observatory
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Harold Masursky	U.S. Geological Survey
Harrison H. Schmitt	Manned Spacecraft Center
Eugene Simmons	Massachusetts Institute of Technology
Donald E. Wilhelms	U.S. Geological Survey

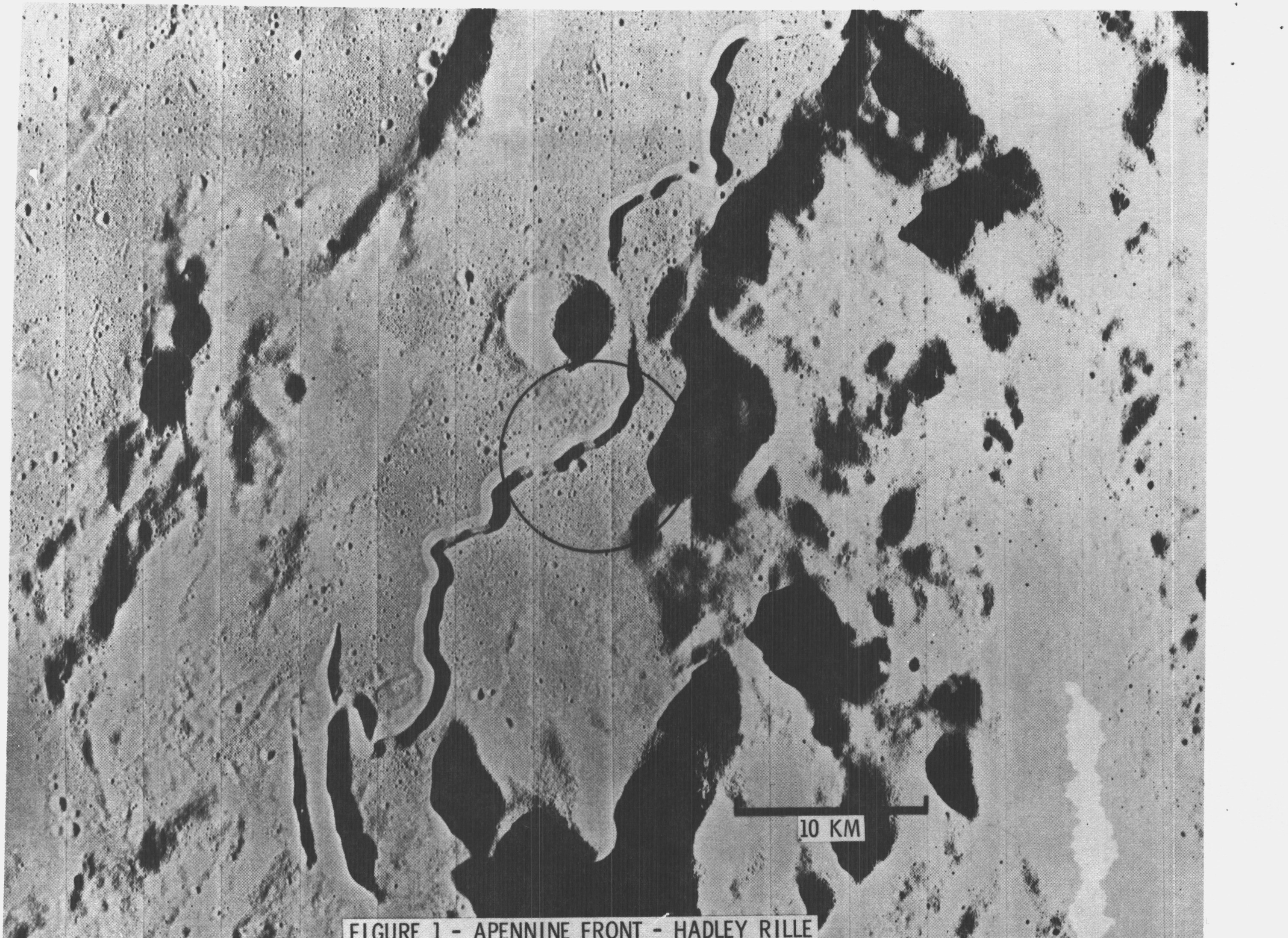

FIGURE 1 - APENNINE FRONT - HADLEY RILLE

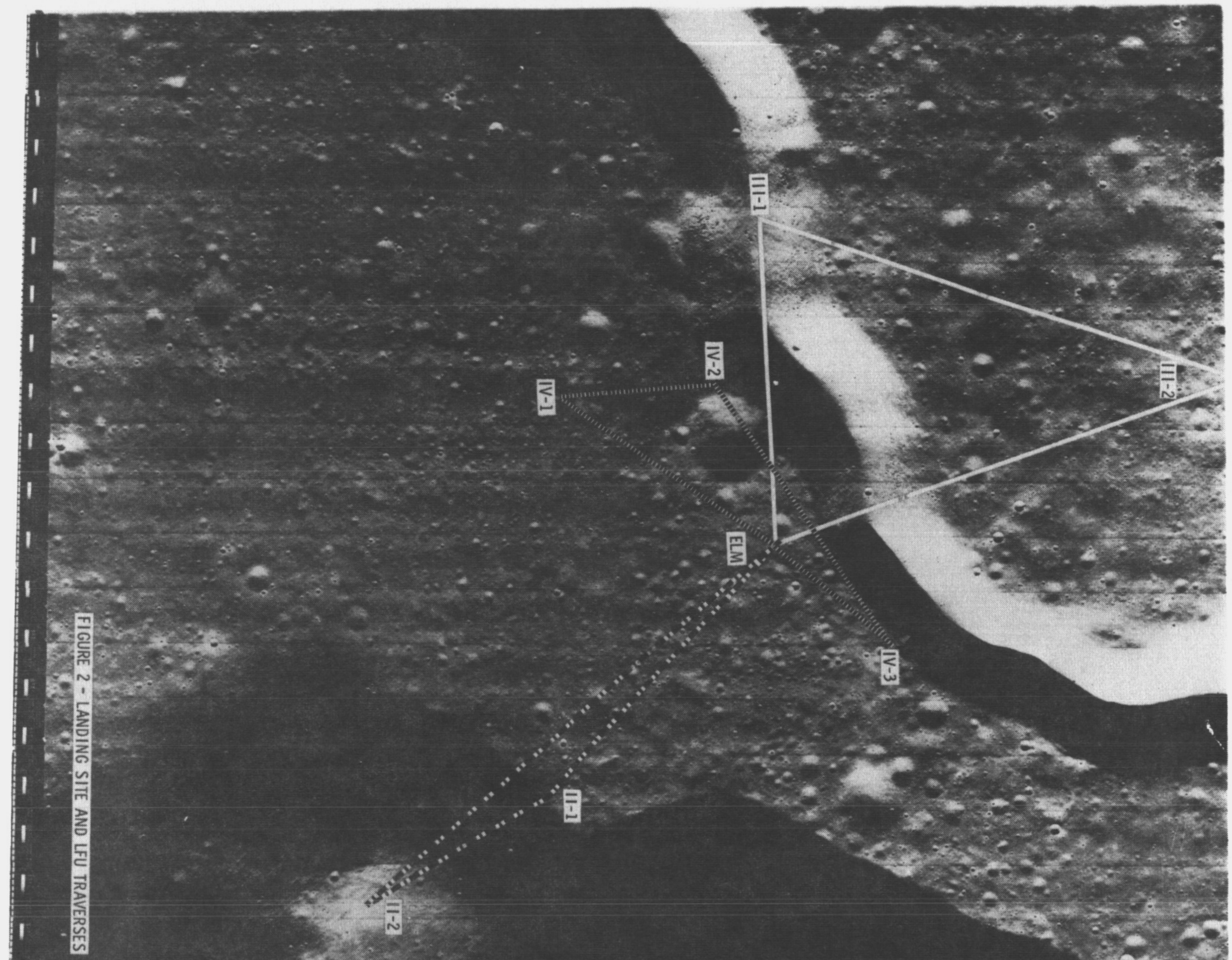

FIGURE 2 - LANDING SITE AND LFU TRAVERSES

NASA-LRC LUNAR ORBITER PROJECT-MISSION V

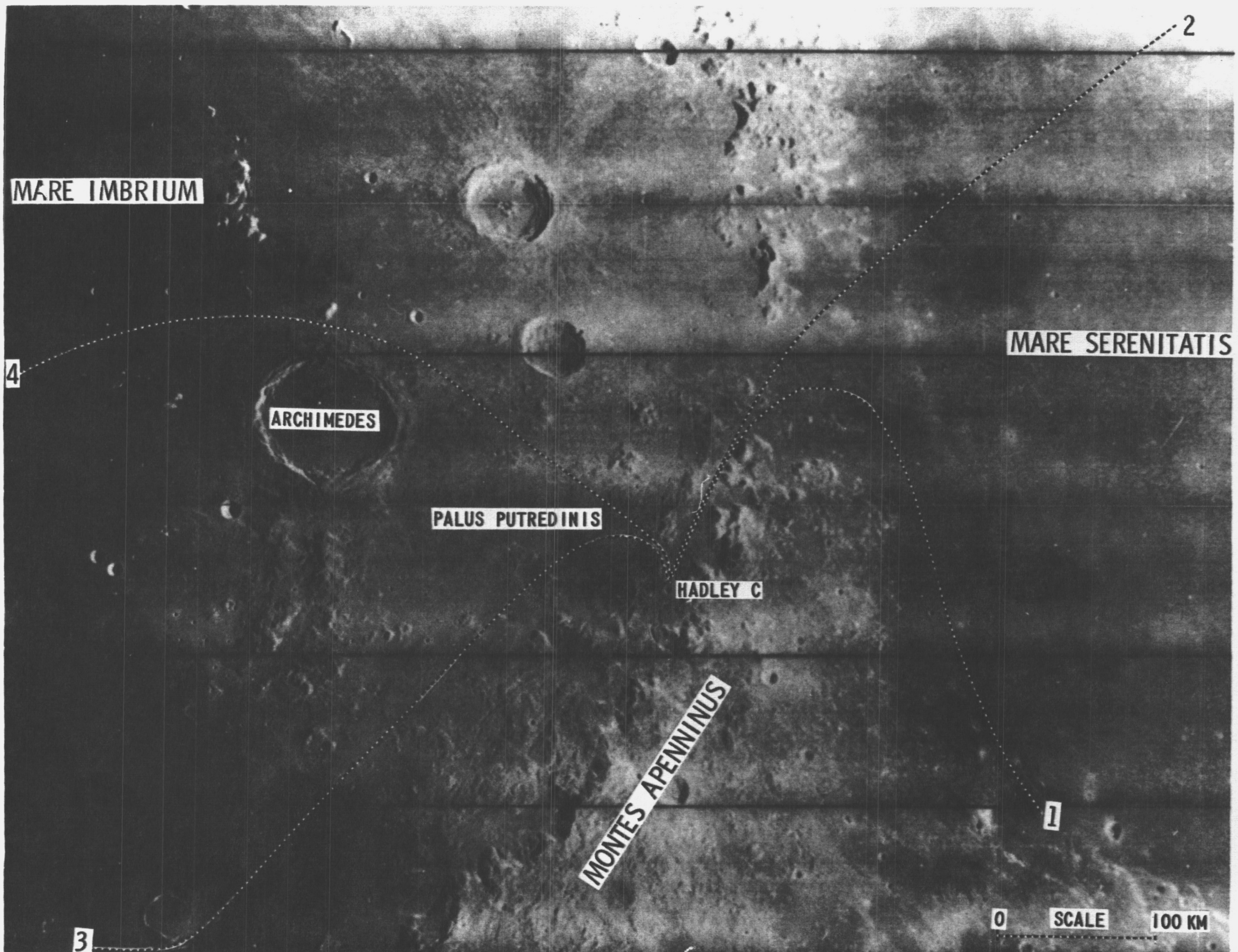

FIGURE 3. POTENTIAL 500 KM ULRV TRAVERSES

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